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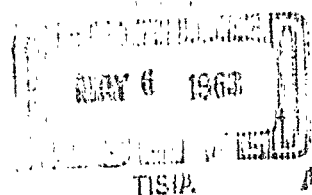
THE DEVELOPMENT OF A THERMIONIC CONVERTER MODULE SUITABLE FOR LIQUID METAL HEATING

FIFTH QUARTERLY TECHNICAL REPORT

APRIL 1963

PREPARED FOR
FLIGHT ACCESSORIES LABORATORY
AERONAUTICAL SYSTEMS DIVISION
AIR FORCE SYSTEMS COMMAND
WRIGHT PATTERSON AIR FORCE BASE
OHIO

PROJECT 8173
TASK NO. 817305-9



(PREPARED UNDER CONTRACT AF33(657)-8005)

PREPARED BY
RADIO CORPORATION OF AMERICA
ELECTRON TUBE DIVISION
LANCASTER, PENNSYLVANIA

AUTHORS W.B. HALL AND J.J. O'GRADY

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FOREWORD

This report was prepared by the Radio Corporation of America on Air Force Contract AF33(657)-8005 under Task Number 817305-9 of Project Number 8173. The work is being administered under the direction of the Flight Accessories Laboratory, Aeronautical Systems Division. Lt. D. Raspet is Project Engineer for the Laboratory.

The report covers the work applied, from 15 December 1962 to 1 April 1963, and represents the efforts of Thermionic Converter Engineering of Power Tube Operations, RCA-Lancaster. W. B. Hall is the Engineering Leader responsible for the technical direction and control of the project under the direct supervision of F. G. Block, Manager.

This report is the Fifth Quarterly Technical Report for the subject contract.

This report is unclassified.

"The work covered by this report was accomplished under Air Force Contract AF33(657)-8005, but this report is being published and distributed prior to Air Force review. The publication of this report, therefore, does not constitute approval by the Air Force of the findings or conclusions contained herein. It is published for the exchange and stimulation of ideas".

ABSTRACT

The program covered in this report is a continuation of the work started in the initial phase of contract AF33(657)-8005. The overall program objective is improved performance, and greater reliability for thermionic energy converters for space applications. The particular objectives include optimization of geometry and ceramic insulation between emitters and the heat source. This work will include the development of a thermionic generator module to develop 3.0 volts of potential from a liquid metal heat source.

The effort during the report period included the evaluation of converter Type A-1198B. This design achieved output power in excess of forty watts at specified conditions.

A three-converter unit was designed to investigate the processing assembly procedures and unwanted low voltage arcs before fabrication of three-volt generator begins.

The overall concept for the three-volt generator has been established. It will be assembled from building block subassemblies to achieve the required performance.

THE DEVELOPMENT OF THERMIONIC CONVERTER MODULE
SUITABLE FOR LIQUID METAL HEATING
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FIFTH QUARTERLY TECHNICAL REPORT

Contract AF33(657)-8005

THE DEVELOPMENT OF THERMIONIC CONVERTER MODULES SUITABLE FOR LIQUID METAL HEATING

SECTION I

INTRODUCTION

The effort covered in this report is a continuation of work toward the overall program objective of improved performance and greater reliability of thermionic energy converters for space applications.

The current program is a continuation of the work done on Contract AF33(616)-7903 and on the initial portion of Contract AF33(657)-8005. The particular objectives of the work in progress are as follows:

1. Continued evaluation of converters developed under the prior portion of Contract AF33(657)-8005.
2. Optimization of converter electrodes, interelectrode wiring and related support structures for a modular concept.
3. Continued investigation of ceramic insulation between emitters and heat source tubing at temperatures between 1200° - 1300° Centigrade.
4. The design, fabrication and evaluation of a three-volt thermionic generator module.

The generator module will be developed to the following objective specifications:

Emitter Temperature	1500 ^o Kelvin maximum
Collector Temperature	650 ^o Kelvin minimum
Efficiency	8.0% minimum
Life Test Time Accumulated	500 hours minimum
Power Density	2.0 watts/sq cm minimum
Power to Weight Ratio	40 watts/pound minimum

SECTION II

SUMMARY

Work has progressed toward each of the several objectives of the current program. Single converters were fabricated and the evaluation continued. A three-unit module is being designed to investigate fabrication and unwanted low voltage arc problems before fabrication of a three-volt generator is begun. The overall concept of the "Three-Volt Generator Module" has been established.

A. Converter Evaluation

Nine converters, Type A-1198B, were fabricated and tested. Power output in excess of one watt per square centimeter was achieved at 1200° Centigrade. Problems in fabrication were encountered and steps taken to eliminate these causes of converter failure. Converter Serial Number 8 was shipped to ASD as an operable unit in accordance with contract requirements.

B. Geometry Investigation

A design of a three-unit module was completed. This unit will be used to determine the configuration of the "Three-Volt Generator Module." Assembly procedures were determined. Methods of low-voltage arc suppression will be investigated and the effectiveness of the ceramic insulator will be evaluated. Jigs and fixtures were designed and materials have been ordered. Construction will begin shortly.

C. Three-Volt Generator Module

The overall design of the Three-Volt Generator Module has been established. The unit will consist of ten converter sections. The sections will be electrically connected in series and within a single envelope.

SECTION III

DETAILED FACTUAL DATA

In accordance with the requirements of Modification 2 to the subject contract, the work has progressed in the separate areas of investigation.

A. Converter Evaluation

In accordance with Modification 1 of the subject contract, a new converter design designated RCA Developmental Converter A-1198B was developed. The overall design of the converter embodied the latest advancements for achieving the overall objectives of the program. The emitter was electrically insulated but thermally bonded to the liquid heat source. The inner heat source tubing is columbium, containing one percent zirconium. The emitter and collector surfaces were designed in the "Saw Tooth" geometry as shown in Figure 1.

Nine converters were fabricated during the report period. These units were evaluated and analyzed with the following results:

1. Converter Serial Number 1

Converter Serial Number 1 employed a planar electrode surface geometry of 39 square centimeters with a 0.030 inch electrode spacing. During the bake-out and exhaust procedure a vacuum leak developed in the heat dam and the converter was shut down. From this initial test, two problem areas were noted:

- a. The heat radiated from the columbium tubing caused the heat dam braze joint temperature to increase above design parameters.
- b. The fin radiator design was conservative, causing the collector to run at a lower temperature than desired.

To overcome these problems the fin diameter was reduced from 4.6 inches to 4.1 inches and a tantalum cylindrical shield was designed to

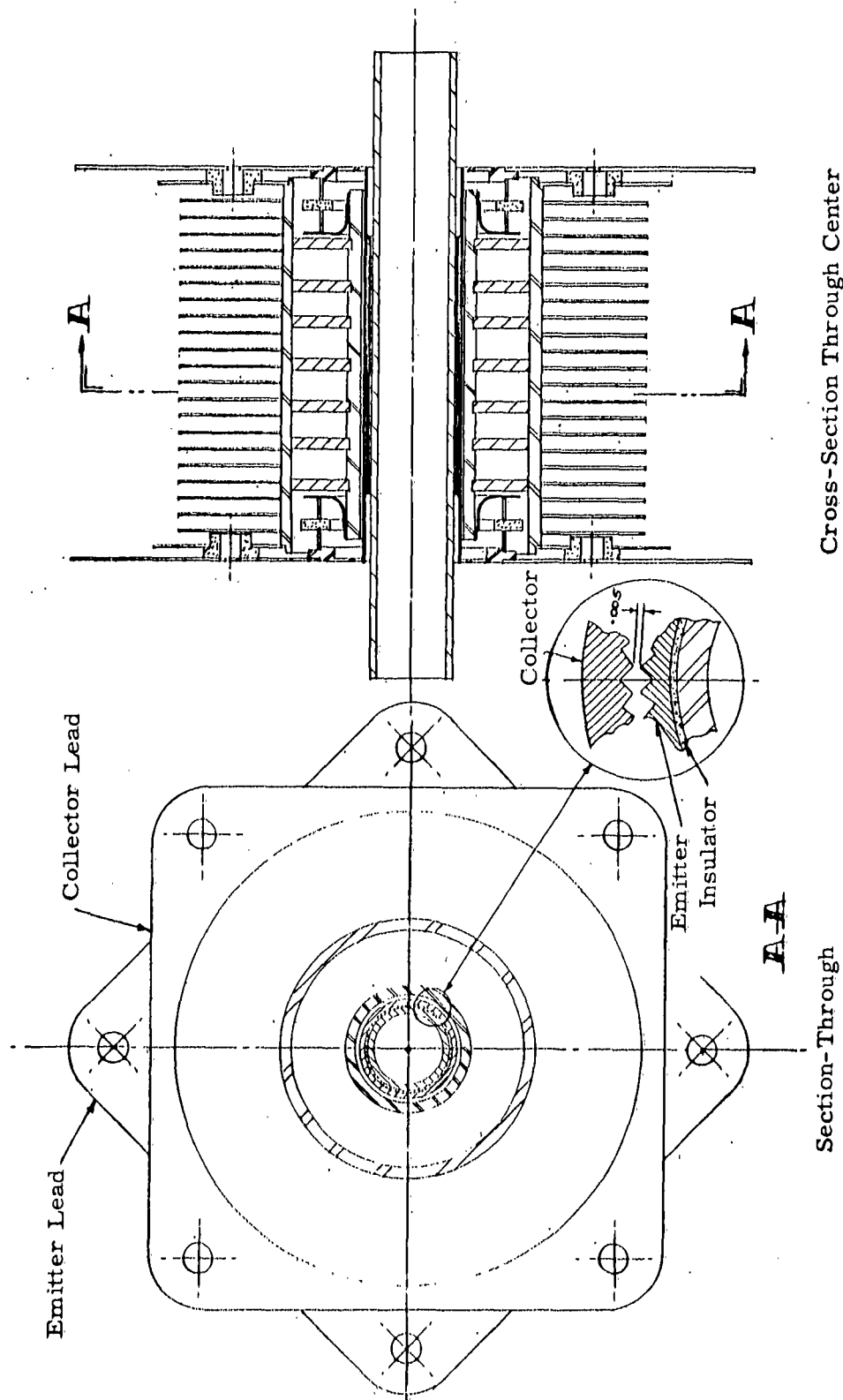


FIGURE 1 - RCA DEVELOPMENTAL CONVERTER TYPE A-1198B

protect the heat dam from radiation heating. The tantalum shield is 0.003 inch thick and 0.800 inch high. This enabled the cylinders to be inserted between the columbium tubing and the heat dam without affecting the electrical insulation.

2. Converter Serial Number 2

Converter Serial Number 2 employed the modifications indicated by Serial Number 1 and also had a "Saw Tooth" electrode surface geometry. After bake-out, the converter was put on test. Its maximum power output was eight watts at 1200° Centigrade. The testing was stopped to remove the initial cesium charge and introduce new cesium into the converter. The second cesiation did not improve the output. At this point it was decided to reprocess the converter and, in addition, to incorporate cesium distillation. During the reprocessing it was noted that the emitter lead had developed a loose bond. A high stress developed by the difference in thermal expansion between copper leads and the molybdenum end plates caused the partial opening of the braze joint. Due to the poor connection, a high resistance developed in the converter circuit. This resistance made it impossible to load the converter properly causing the low power output. To correct this problem, the copper was replaced by molybdenum so that the thermal expansion of the emitter lead would match that of the molybdenum part to which it is brazed.

3. Converter Serial Number 3

During the brazing of the emitter to collector assembly of Converter Serial Number 3, the assembly was brazed to the fixture. In the removal of this assembly, the heat dam was broken. To prevent subsequent assemblies from brazing fast, a ceramic spacer was incorporated in the jig.

4. Converter Serial Number 4

During the emitter to collector assembly braze of Converter Serial

Number 4, the emitter insulation became shorted. Burrs were observed in machined parts. Since the short was intermittent the assembly was scrapped. Additional controls have been incorporated into the process which will prevent reoccurrence of this failure.

5. Converter Serial Number 5

This converter had been completely fabricated and after the exhaust tubulation was attached a vacuum leak developed at the heat dam. The problem was accidentally caused during the rf brazing. Improvement in technique has eliminated this problem.

6. Converter Serial Number 6

Converter Serial Number 6 employed a planar electrode surface (39 square centimeters in area) and a distillation appendage. Dual cesium capsules, a tantalum cylindrical shield and high purity nickel for the collector were employed in this converter and all subsequent converters. During the initial testing, using distillation, 20 watts of useful output power were obtained. (The emitter to columbium tubing had a resistance of 1500 ohms). The low power level was caused by insufficient cesium for converter operation due to the cesium distillation technique. The distillation appendage was redesigned to prevent excessive cesium capture. After the distillation appendage was removed, the converter power output reached 45 watts in static testing and 43 watts in dynamic testing. The dynamic test results are shown in Figure 2. At one point during the converter testing, 47 watts was reached at an emitter temperature of 1250^o Centigrade. Testing was stopped after approximately 50 hours of operation. This unit will be employed as a life test unit when suitable equipment currently being fabricated under RCA sponsorship is completed.

7. Converter Serial Number 7

The electrode surface geometry of Converter Serial Number 7 was

$T_e = 1200^\circ \text{ Centigrade}$

$T_c = 550^\circ \text{ Centigrade}$

$T_{cs} = 285^\circ \text{ Centigrade}$

Emitter Area = 39 Square Centimeters

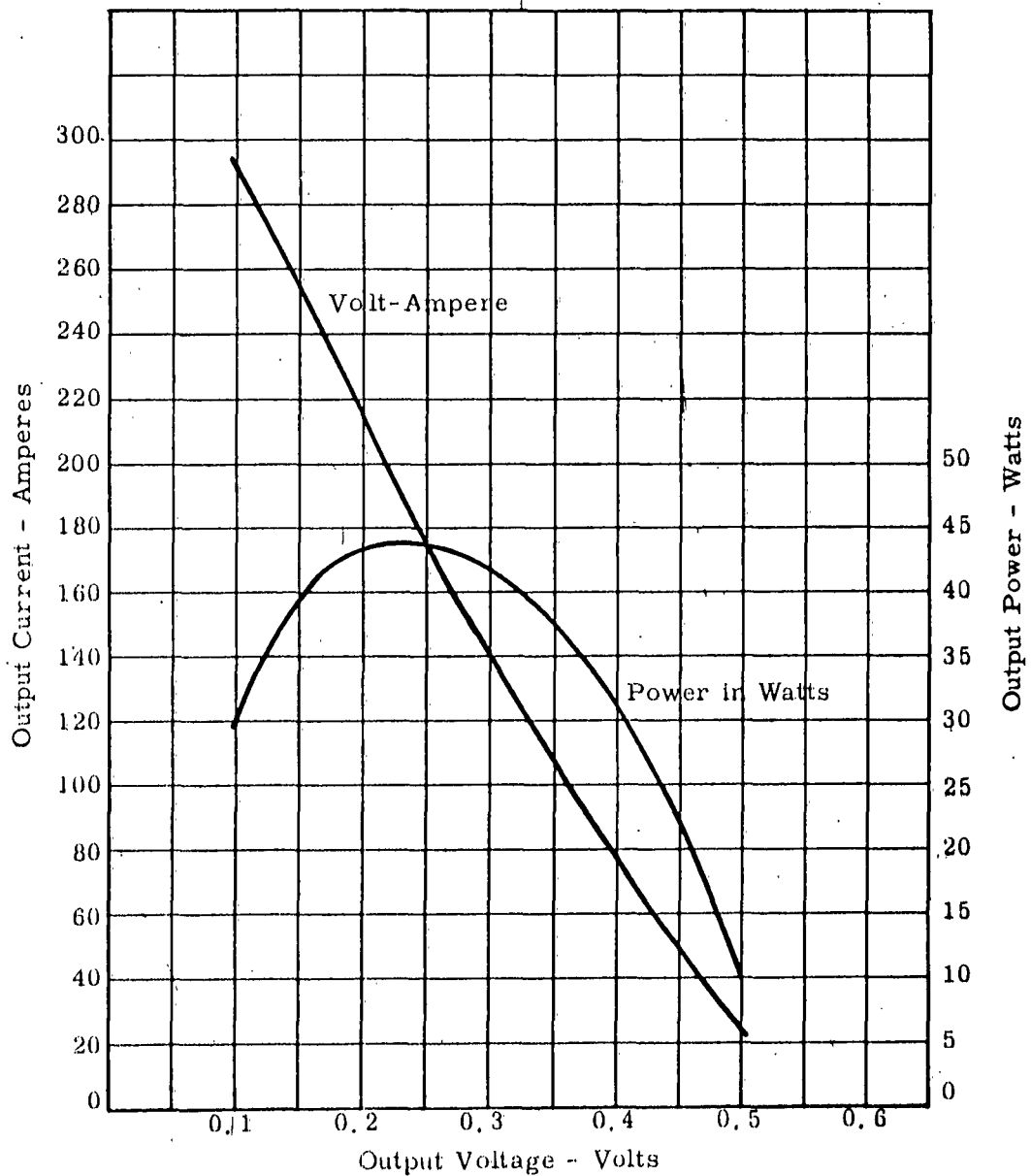


FIGURE 2 - OUTPUT CHARACTERISTICS
CONVERTER TYPE A-1198B, SERIAL NUMBER 6

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planar and similar to Converter Serial Number 6. During distillation and after removal of the distillation appendage the maximum power was only 20 watts at 1200° Centigrade. The output level appeared to be current limited and when the power began to decrease, the converter was shut down. Examination revealed a vacuum leak at the ceramic seal. A metalizing problem which was easily solved by closer processing control caused this failure.

8. Converter Serial Number 8

Converter Serial Number 8 employed a "Saw Tooth" electrode surface geometry of 55 square centimeters of emitter area (projected area 39 square centimeters). During the distillation procedure, a power output of 44 watts at 1200° Centigrade was obtained. After removal of the distillation appendage, but still using the first cesium capsule, 44 watts were obtained during static testing. The dynamic testing, Figure 3, showed that the power level increased to 47 watts at 1200° Centigrade. This difference in output power is caused by slight variation in optimum conditions which affect overall converter power levels. After approximately 20 hours of operation, all appendages were removed, the converter was given a final test and shipped to ASD according to contractual requirements.

9. Converter Serial Number 9

Converter Serial Number 9 with "Saw Tooth" geometry, similar to Serial Number 8, was fabricated as a backup for converter Number 8. It will be exhausted and life tested when life test equipment is completed.

B. Geometry Investigations

1. Ceramic Insulation

Tests were developed to measure the thermal drop through the insulated emitter assembly. The test procedure is outlined below.

$T_c = 1200^\circ \text{ Centigrade}$

$T_c = 470^\circ \text{ Centigrade}$

$T_{cs} = 220^\circ \text{ Centigrade}$

Actual Emitter Area = 55 Square Centimeters

Projected Emitter Area = 39 Square Centimeters

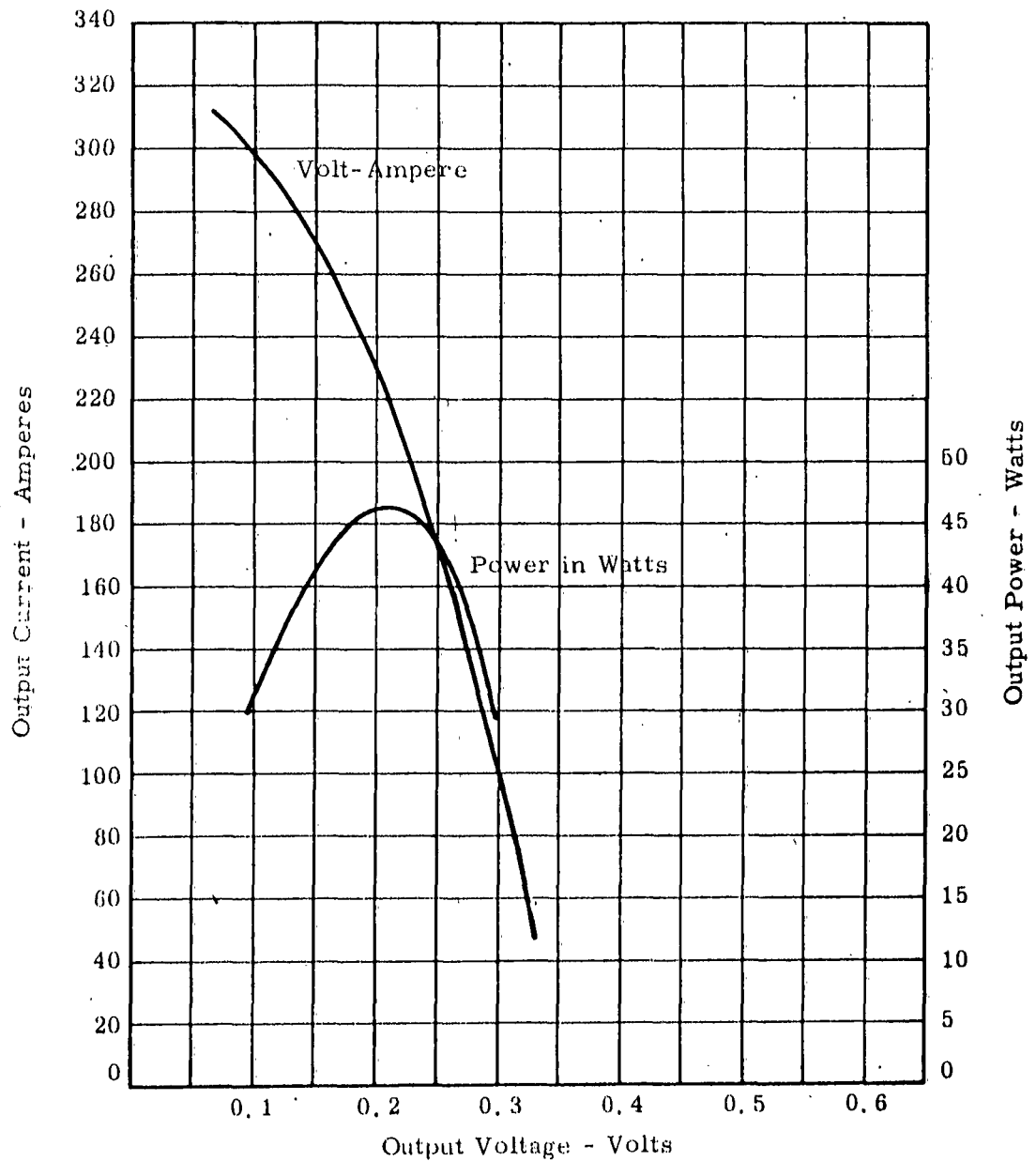


FIGURE 3 - OUTPUT CHARACTERISTICS
CONVERTER TYPE A-1198B, SERIAL NUMBER 8

TABLE I
ANALYSIS OF CONVERTER OPERATION
TYPE A-1198B

Converter Serial No. 6

Output Power During Distillation (DC test) 20 watts
(118a @ 0.17V)
Te = 1224° C
Tc = 435° C
Tcs = 305° C

Output Power After Removal of Appendage (DC test) 45 watts
Te = 1250° C Estimated Emitter Temperature (150a @ 0.3V)
Tc = 625° C
Tcs = 305° C

Output Power After Removal of Appendages (AC test)	V	I	P
	0.10	280	28
	0.15	255	38.5
	0.20	216	43
Te = 1200° C Estimated Emitter Temperature	0.25	172	43
Tc = 550° C	0.30	140	42
Tcs = 300° C	0.35	108	38
R = 500 ohms	0.40	80	32
	0.45	56	25

Results of AC test shown in Figure 2

Converter Serial No. 8

Output Power During Distillation (DC test) 44 watts
(175 @ 0.25V)
Te = 1180° C
Tc = 450° C
Tcs = 230° C

Output Power After Removal of Appendages (AC test) 47 watts
Ref. Figure 3

Output Power After Removal of Appendages (DC test) 44 watts
Te = 1155° C
Tc = 445° C
Tcs = 205° C

- a. The emitter was run in a vacuum environment at a pressure of approximately 10^{-5} Torr.
- b. The insulated emitter incorporated a hole drilled through the insulation and a thermocouple (B1) attached at this point. (ref. Figure 4)
- c. A second thermocouple (B2) was attached to the emitter surface approximately 90° from the first thermocouple.

The thermocouples were platinum, platinum 13 percent rhodium.

In the first test an attempt was made to determine the temperature differential between the inner and outer surfaces directly. One platinum wire was attached to each surface and a platinum 13 percent rhodium wire was attached across the platinum wire. The ends of the platinum wire were connected to a potentiometer to determine the millivolt differential. When the emitter surface reached 950° Centigrade (optical pyrometer measurement), this differential dropped to zero. By reversing the leads and increasing the temperature, a differential of 1.0 millivolt at 1200° Centigrade was observed. This corresponds to a 60° Centigrade temperature drop. The polarity change indicated that the outer surface had become hotter than the inner surface. This improbable result led to the development of the second test method.

The second test procedure was similar to the first, except that the thermocouple leads for each surface were extended out of the vacuum chamber so that the temperature of each surface could be monitored. Thermocouple B1 showed an 1140° Centigrade temperature while B2 showed a 1200° Centigrade temperature. Once again a 60° Centigrade drop was indicated and the outer surface was hotter than the inner surface.

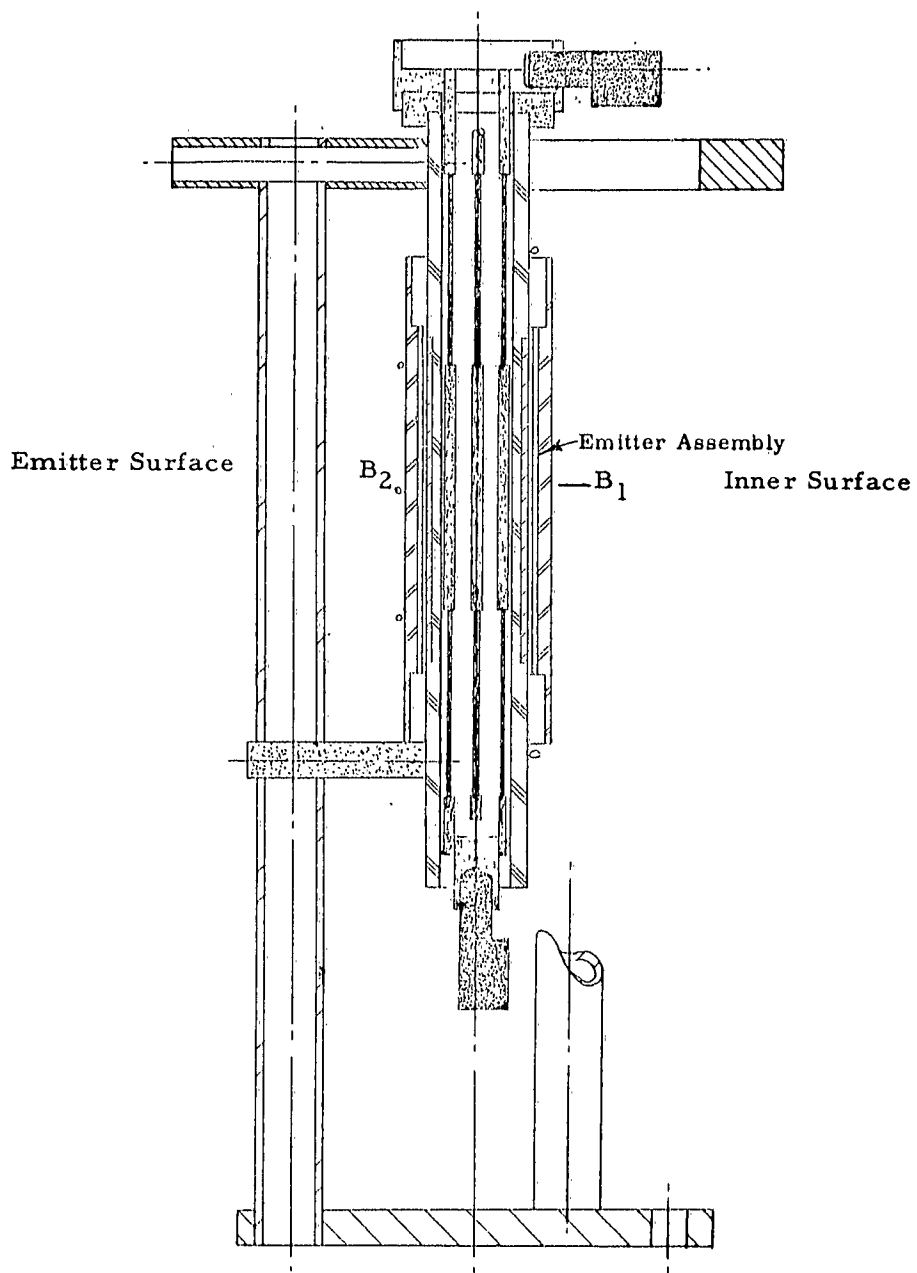


FIGURE 4 - TEST FIXTURE FOR TEMPERATURE GRADIENT
OF EMITTER ASSEMBLY

Since this result is completely unreasonable, the test set-up will be reevaluated. Tentatively, it is thought that the result is due to a poor contact between the thermocouple bead and the surface, or to the formation of an alloy on one surface of the thermocouple, causing it to change its characteristics.

The test will be rerun and results reported in the next report period.

2. Three-Converter Module

In order to isolate and solve the fabrication and processing problem presented by the program objective, a three-converter module was designed. This unit consisted of three building blocks that can be supplemented with additional similar units to obtain the desired output characteristics. The effort during the current report period covered three major areas: (1) determination of the assembly procedures, (2) suppression of unwanted low-voltage arcs, and (3) selection and ordering of materials.

The design of the module will incorporate the following sequence of operations:

- a. The bottom end-support made of Columbium sheet will be electron-beam welded to the center Columbium tubing. See Figure 5.
- b. The cast emitter assembly will be made from a structure consisting of two concentric molybdenum tubings with sapphire insulation cast between them. Three emitter assemblies will be machined from one of these structures. See Figure 6 and Figure 7.
- c. The columbium emitter lead will be fusion-bonded to the emitter assembly. See Figure 8.

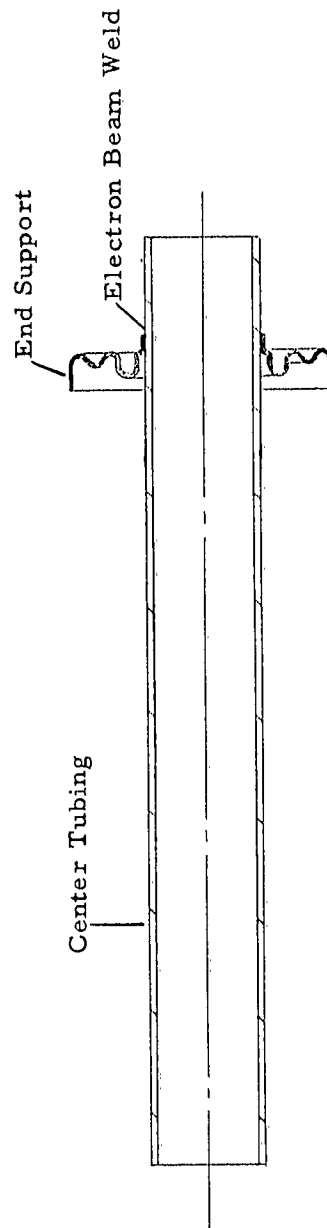


FIGURE 5 - CENTER TUBING - END SUPPORT ASSEMBLY

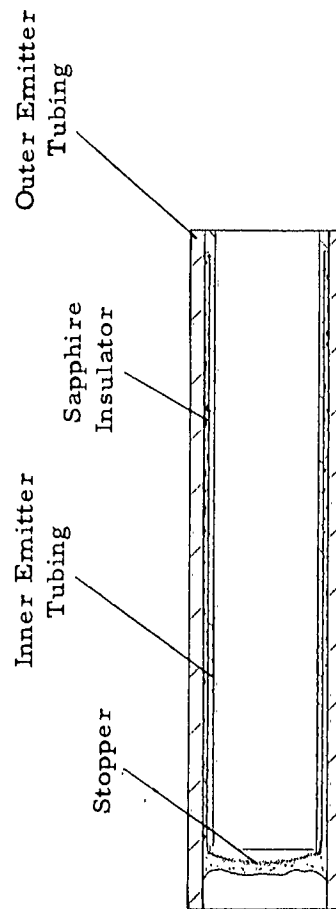


FIGURE 6 - CAST EMITTER ASSEMBLY

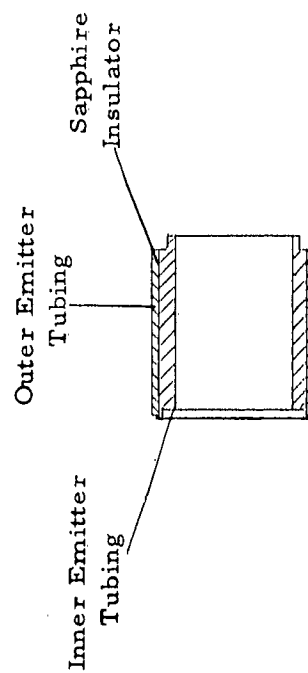


FIGURE 7 - EMITTER ASSEMBLY

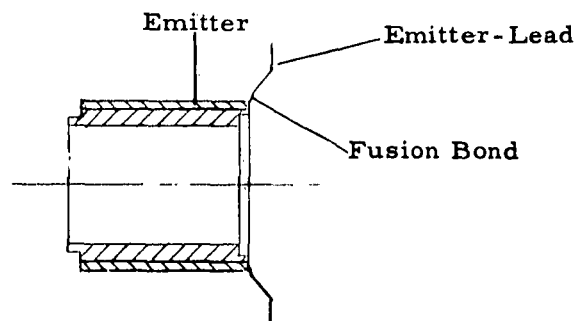


FIGURE 8 - EMITTER, EMITTER-LEAD ASSEMBLY

- d. An assembly consisting of the above fusion-bonded assembly, ceramic insulation ring, and isolation rings will be made for each of the three converters of the module. See Figure 9.
- e. The collector assembly will be made of molybdenum with the nickel collector fusion-bonded to it. See Figure 10.
- f. The center tubing end-support assembly, the collector assembly, the assembly described under d above, and the remainder of the module except the fins and the window assembly, will then be fabricated. See Figure 11.

In the first converter, the emitter and the collector will be keyed together with sapphire balls to assure unidirectional heat expansion of the structure. See Figure 11.

- g. The I. D. of the top end support will be electron-beam welded to the center tubing. See Figure 11.
- h. The fins and the nickel adaptor for the window assembly will then be brazed on the assembly. See Figure 12.
- i. The window assembly consisting of the cesium appendages, sapphire window and cesium distillation will be rf brazed onto the module.

All materials necessary to build the three-converter module have been ordered. Deliveries are expected between April 5 and April 15, 1963

3. Method of Suppression of Low-Voltage Arcs

Since the ionization potential of cesium is 3.89 volts, the three volts developed within the module, plus the difference in work function on the support structures, will develop a potential suffi-

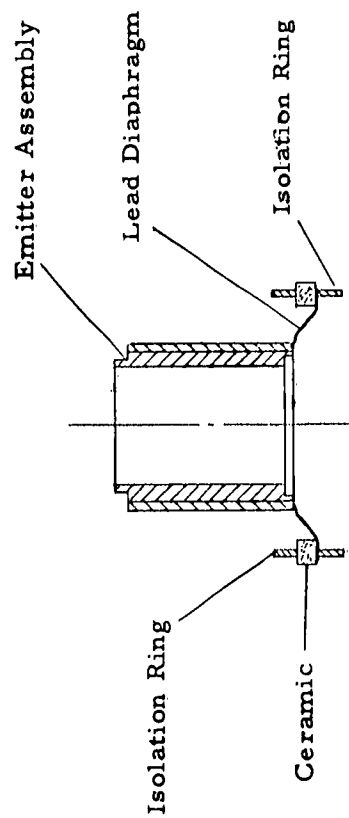


FIGURE 9 - EMITTER-LEAD SUB-ASSEMBLY

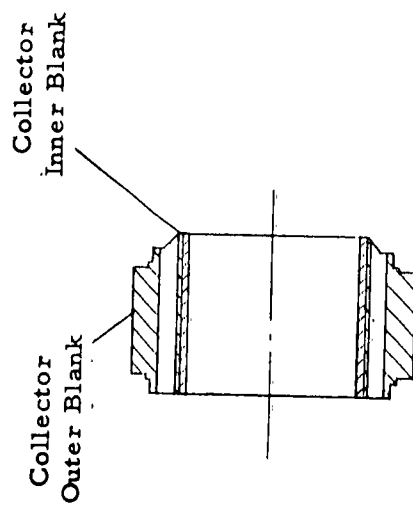


FIGURE 10 - COLLECTOR

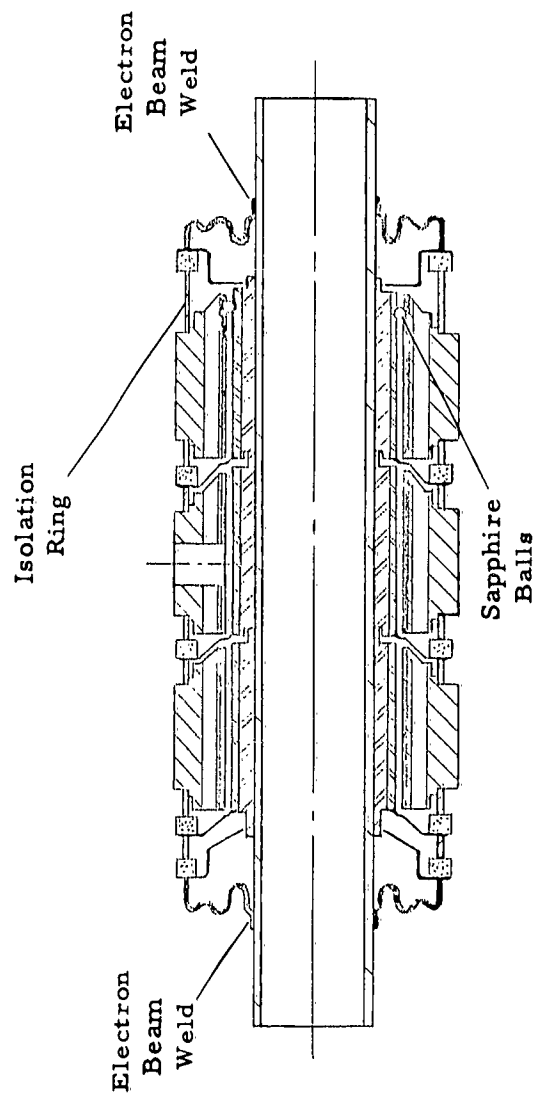


FIGURE 11 - THREE-CONVERTER ASSEMBLY

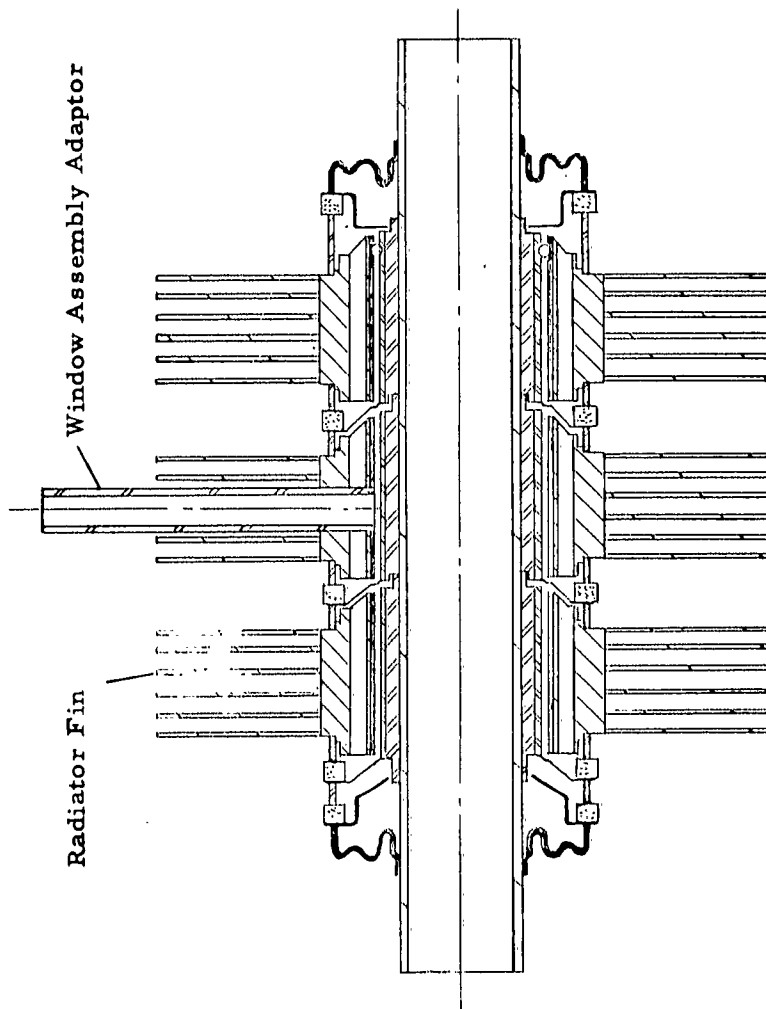


FIGURE 12 - THREE CONVERTER MODULE

cient to cause direct ionization and thus electrical shorting between separate converters of the module. To overcome this problem, the individual converters in the module must be shielded from each other in such a manner that a high potential cannot develop between any two converters.

To obtain this shielding, the surface of each emitter-lead which faces the next converter will be plasma-sprayed with alumina. The top shield and the bottom shield serve to suppress arcing between the center tubing and the first and the last converter as shown in Figure 13. Furthermore, the longitudinal holes on the collectors and on the emitter leads, through which the module will be evacuated, will be displaced from each other by 15 degrees to minimize the possibility of arcing through the structure.

4. Testing

DC testing of the first three-converter module will be done during the next report period. In these tests the module will be heated by an electric heater made of tungsten wire. See Figure 14. This heater is identical to the one used to test converter A-1198B. An output in the order of one volt is expected.

C. Three-Volt Generator

The overall concept has been established for a thermionic generator capable of delivering useful power at a potential of 3.0 volts. The general approach used in the assembly of the Three-Unit Module will be employed. Additional center sections will be added in series to obtain the required voltage output. All preliminary determination of manufacturing and processing techniques will be obtained with the Three-Unit Module. This information will then be applied to the construction of the Three-Volt Generator.

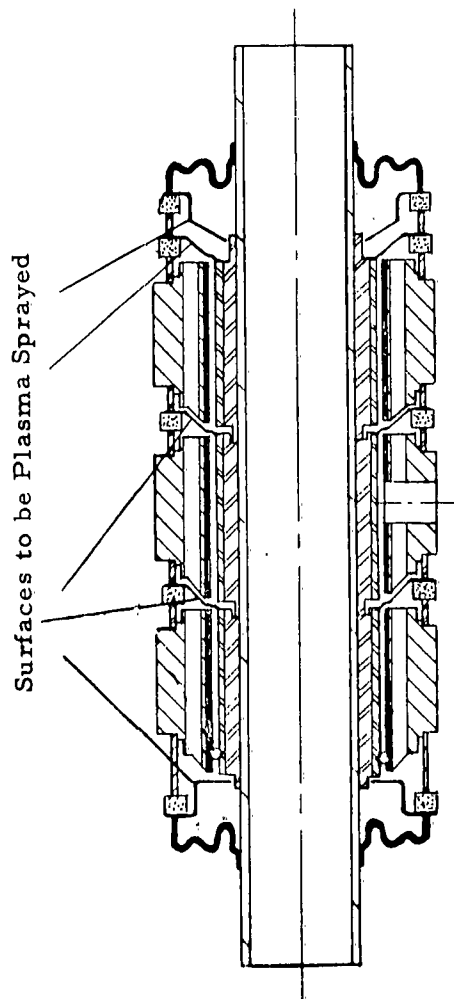
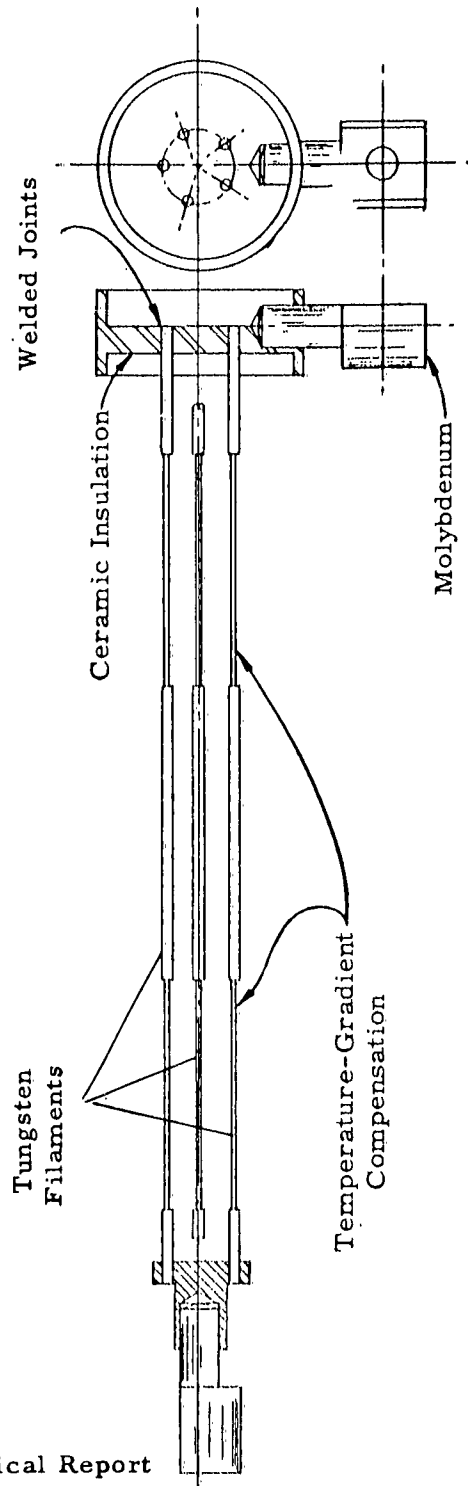


FIGURE 13 - AREAS TO BE PLASMA SPRAYED



**FIGURE 14 - ELECTRICAL HEATER FOR USE WITH
THERMIONIC CONVERTER MODULES**

A special heater will be designed to deliver the required power to the Three-Volt Generator to achieve operation at the design temperature. This heater will incorporate compensation to assure a correct temperature distribution on the emitter surface.

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